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Ergonomics Hazards Analysis of Linemen's Power Line Fixing Work in China

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This study used qualitative and quantitative methods, such as OWAS (Ovako working posture analysis system) and behavior observation, to analyze musculoskeletal disorder (MSD) risk factors of power line fixing work in China. Video-based sampling was used to record and analyze the frequency and posture of on-pole activities. Those key subtasks showed ergonomics characteristics of on-pole fixing tasks. Insulator-fixing was the longest subtask (33% of total working time). Bar-installing was the second longest (26% of total working time). It was evident that bar-installing and insulator-fixing were full of hazardous risks. The action categories of the 2 subtasks were higher than of the other ones. The 2 subtasks were also time-consuming, difficult and induced MSDs. Assistant linemen faced more hazardous factors than chief linemen.

ergonomics hazards linemen musculoskeletal disorders

1. INTRODUCTION

Musculoskeletal disorders (MSDs) such as back injuries caused 32% of health-related absenteeism in Germany in 1992 and about one fourth of all compensation payments in the USA [1]. Survey research at individual worksites also typically demonstrated higher rates of MSDs than those recorded by the local workers' compensation system [2, 3, 4]. Even though attention was paid to ergonomics and there was an increasing understanding of ergonomics issues, MSDs in the workplace remained a considerable problem [5]. Comparable data on other industries in China showed that nonfatal injury rates in the power industry were lower than in construction and mining, but higher than in transportation, manufacturing and services. Although workers in the power distribution industry directly indicated that low back, shoulder, and wrist strain was common, little was precisely known about how strain occurred and how it could be prevented. There were almost no manuals to guide a lineman on how to avoid MSDs in power line fixing work.

Power line fixing work in this paper indicates on-pole fixing tasks of linemen; it excludes digging pits, transporting materials, erecting poles, fixing transformers and other services on the ground. This work has long been recognized as a dangerous occupation especially in areas where the industry employs a significant population. In most cases, a lineman has to do the job with injuries without reporting them to the employer. In contrast to acute events, cumulative trauma injuries are typically not reported. Such under-reporting, coupled with a highly mobile workforce and dynamic exposure conditions, also makes it difficult to conduct epidemiological research on

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the etiology of work-related MSDs. Though local surveillance efforts have increased, systematic data on nonfatal injuries, particularly MSDs, are still insufficient in the national power industry of China. The study on safety and health in occupational epidemiology continues.

A study on ergonomics factors describes and analyzes what scenarios and factors are most likely responsible for strain in linemen; it can also identify opportunities to prevent recognized hazards. Manual tasks can be evaluated using various well-documented approaches: biomechanical, psychophysical, epidemiological and physiological [6]. These approaches have helped determine primary risk factors involving manual handling and resultant musculoskeletal injuries. Many case studies investigated manual activities in a variety of work situations [7]. In most cases a combination of two or more methods was used to minimize effects of relying on a single approach. Development of models robust to changes in whole-body posture should do much to increase our insight into the structure and function of the musculoskeletal system [8]. Certain occupational risk factors, namely awkward postures, repetition and forceful exertions, contribute to the occurrence of musculoskeletal injury and illness [9]. Identifying subtasks and quantifying risks of work processes in the power industry should result in an effective analysis of factors inducing MSDs.

This study is based on a series of systematic ergonomics observations of specific power line fixing work environments and generic work processes. The purpose of this paper is to describe subtasks of on-pole work associated with various types of operations and to analyze characteristics of different subtasks. OWAS (Ovako working posture analysis system) was used to assess the level of hazardous risks. Then the frequency and duration of activities were recorded and analyzed with video-based activity sampling. At the same time, assistant and chief linemen's work was analyzed and compared.

2. METHODS

2.1. Participants

Thirty linemen from seven power line project teams in the cities of Xi'an and Baoji of the Shaanxi province participated in the study. Individual workers were informed about the study; those who wished not to be observed were excluded. The statistical characteristics of the observed linemen were as follows: height 172.3 ± 8.5 cm; weight 63.7 ± 6.5 kg; length of service 4.8 ± 3.6 years; duration of task 220 ± 50 min. This was only a case study, and may not have been representative of typical projects and crews in power line construction. Usually, there are a chief lineman and an assistant lineman on a pole. Two linemen have to co-operate to finish fixing work. The two linemen's work looks very similar. They also face similar risk of hazard. Linemen in a 10-kV power distribution line project participated in this study. The poles were cylindrical, concrete, 15 m above the ground. The observers in the study came from the Industrial Engineering department of the Xi'an Jiaotong University and were experienced.

2.2. Procedure

Although power line fixing work is relatively routine, there is no work cycle of regular content and duration. The variables that likely affect ergonomics factors (pole size, distance between poles, size and type of power line, size and type of insulators, etc.) can differ substantially. Thus, OWAS was used to characterize the postural risk factors associated with the observed tasks, although without a formal work sampling protocol. Preliminary observations were used to create a checklist of ergonomics risk factors. This data collection was done with two project teams observed for 2 days in Xi'an. The teams employed a high proportion of experienced workers. The final version of the checklist was used to collect data from 30 individual linemen in five fixing project teams: three teams in Xi'an and two in Baoji.

2.3. Action Duration Analysis

Observer version 5.0 (Noldus Information Technology, The Netherlands)[1] is a professional manual motion analysis tool. It can record and analyze a subject's motion posture in detail. The tool was used to record the subject's motions and to analyze postures, action duration, action sequence and action frequency. Subtasks can be divided and described with Observer as well.

2.4. Working Posture Analysis

OWAS can differentiate risks which can induce MSDs [10]. It can code each posture of the human body and its coding can be analyzed to estimate action categories of working postures. The action categories consist of four grades: AC1, AC2, AC3 and AC4 (Table 1). Hazardous postures with AC3 or 4 should be improved as soon as possible or immediately [11].

TABLE 1. OWAS (Ovako Working Posture Analysis System) Action Categories (ACs)

Category	Postural Load	Improvement Measures
AC1	normal	not necessary
AC2	increased	necessary
AC3	high	as soon as possible
AC4	very high	immediately

Figure 1. Left lineman's code: 33142, AC4; right lineman's code: 24131, AC2. *Notes.* AC—action category.

Figure 2. Left lineman's code: 43352, AC4; right lineman's code 12221, AC2. *Notes.* AC—action category.

In this study, it was very important to do field investigation on power line fixing and to search for relevant data such as work flow, work duration, action frequency, etc. The working process was recorded. The working scenes from the video were intercepted every 30 s. Then, the neck, hands, back and thighs of linemen and exerted force were separately coded according to the working postures. Hazardous risks were estimated with a coding system referring to the postural risk estimation method proposed by Graham and Nicola [12]. The data were analyzed with SPSS version 11.5, the significance was <.05. Five video samples were used to analyze the working process. Every video sample was ~2 h long. Figures 1–2 illustrate examples of coding.

3. RESULTS

3.1. Power Line Fixing Subtasks and Key Activities

The working process included a series of subtasks, such as digging, pole-erecting, climbing, bar-fixing, insulator-fixing, line-drawing, etc. The paper focuses on the last four of those. Table 2 lists body areas, risk factors, estimated force and the mean duration of subtasks. The mean

[1] http://www.noldus.com

TABLE 2. Body Areas, Risk Factors, Estimated Force and Mean Duration of Subtasks

Subtask	Body Areas Strained	Risk Factors	Estimated Average Force/Load	Mean Duration of Subtask (%)
Climbing	ankle/knee	bending, high force	low	6
Bar-installing	shoulder	high force, above shoulder	medium	26
Insulator-fixing	shoulder/low-back/neck	above shoulder, bending	medium	33
Line-drawing	low-back/shoulder/wrist	twisting, high force, pinch, grip	high	20
Others				15

Notes. low = 0–5 kg, medium = 6–20 kg, high >20 kg.

TABLE 3. Mean Duration of Key Activities of 4 Subtasks

Subtask	Key Activity	Mean Duration (s)
Climbing	tie strap	62
	put on stirrup	95
	climb pole	206
Bar-installing	sling bar	283
	fix accessory	345
	adjust bar	247
	fix bar	412
Insulator-fixing	sling insulator	235
	fix accessory	636
	fix insulator	563
Line-drawing	sling line	63
	fix accessory	446
	drag line	336

duration of key activities of the four subtasks can be calculated (Table 3).

Insulator-fixing and line-drawing involved fixing three insulators and drawing different lines 3 times. The process of climbing up and down the pole was time-consuming. In the process of bar-installing, the duration of fixing accessory was the longest. The lineman had to screw bolts to fix the accessory and the bar. This kind of work required more time and patience because it was necessary to fasten the bar a little and then gradually adjust it to the best position with a hammer. Finally, the lineman had to screw individual bolts to fix the bar completely.

3.2. OWAS Analysis Results

3.2.1. Hazardous action analysis

Table 4 lists the proportion of hazardous actions and the relevant ACs. The chief lineman often bent his neck forward because he had to pay attention to the object of his work. In addition, many tools and materials had to be slung up from the ground. Therefore, the lineman had to bend his neck forward frequently. The main reason for the action of bending backward was that the power line was above the lineman's head and the lineman had to bend his neck backward to focus on the work object. The chief lineman mostly bent his back forward, especially his low-back. It was important for the lineman to keep his balance on the pole through twisting and bending low-back with the help of a safety strap. It was very risky for the worker to take such actions to finish the task. When the lineman looked up to draw a power line above his head, he had to raise his arms to reach the working position. The stirrups could not stay at the same altitude: the lineman had to bend a leg while the whole body load remained almost concentrating on the other foot. There was no significant difference of un-neutral posture percentages between chief and assistant linemen. The proportion of un-neutral postures of the chief lineman's neck was 34.6% and the assistant lineman's 38.8%. The proportion of un-neutral postures of chief lineman's back was 70.7% and assistant lineman's 68.6%. The neck and back were the body parts which had a higher proportion of hazardous postures. Therefore, the neck and back were exposed to more hazardous risk than other body parts.

Single-action analysis showed that the neck and back faced crucial risks. So the neck and back became the key variables in the compound-action analysis. Six compound postures were abstracted in Table 5.

TABLE 4. Proportion and Action Categories (ACs) of Hazardous Actions

		Chief Lineman		Assistant Lineman	
Body Part	**Posture**	**Proportion (%)**	**AC**	**Proportion (%)**	**AC**
Neck	bend backward	11.6	2	15.2	2
	bend forward	13.3	1–2	11.5	1–2
	bend left/right	8.8	1–2	9.3	1–2
	turn around	0.9	1	2.8	1
Arm	over-shoulder	28.1	2	25.6	2
Back	bend forward	33.5	1–2	31.4	1–2
	twist	21.6	2	24.3	2
	twist and bend	15.6	2	12.9	2
Leg	bend 2 legs	7.2	1–2	23.6	2
	bend single leg	22.1	2	11.5	2

Notes. The analysis is based on 230 snapshots of linemen's postures. The frequency presented here is the mean of frequencies of samples. The denominator of proportion is the number of total snapshots. Each posture may have several hazardous actions. Therefore, the sum of proportions regarding different postures does not equal one.

TABLE 5. Comparison of Compound Postures of Chief and Assistant Linemen

Posture		Chief Lineman		Assistant Lineman	
Neck	**Back**	**Frequency**	**(%)**	**Frequency**	**(%)**
bend forward	bend forward	58	(25.2)	55	(23.9)
bend forward	twist	29	(12.6)	20	(8.7)
twist	bend and twist	25	(10.9)	12	(5.2)
bend forward	bend and twist	9	(3.9)	10	(4.4)
twist	twist	8	(3.5)	9	(3.9)
bend left/right	twist	7	(3.0)	22	(9.6)

Notes. The analysis is based on 230 snapshots of linemen's postures. The frequency presented here is the mean of frequencies of samples. The denominator of proportion is the number of total snapshots. Each posture may have several hazardous actions. Therefore, the sum of proportions regarding different postures does not equal one.

3.2.2. Comparison of chief lineman and assistant lineman

The chief lineman co-operated with the assistant lineman to finish tasks. Generally, their work looked similar. However, the hazardous risk was different. The frequency and proportion of relevant actions corresponding to different ACs were calculated and are shown in Table 6. Moreover, Figure 3 depicts a comparison of proportions for AC2, AC3 and AC4. Although there was no significant difference of un-neutral posture percentages between chief and assistant linemen, the frequencies of AC3 and AC4 of the assistant lineman were higher than the chief's. This showed that the assistant faced more hazardous exposures than the chief.

TABLE 6. OWAS (Ovako Working Posture Analysis System) Action Category (AC) Distribution of the Whole Body

	Chief Lineman		Assistant Lineman	
AC	**Frequency**	**(%)**	**Frequency**	**(%)**
AC 1	99	(43.0)	103	(44.8)
AC 2	80	(34.8)	64	(27.8)
AC 3	23	(10.0)	28	(12.2)
AC 4	28	(12.2)	35	(15.2)

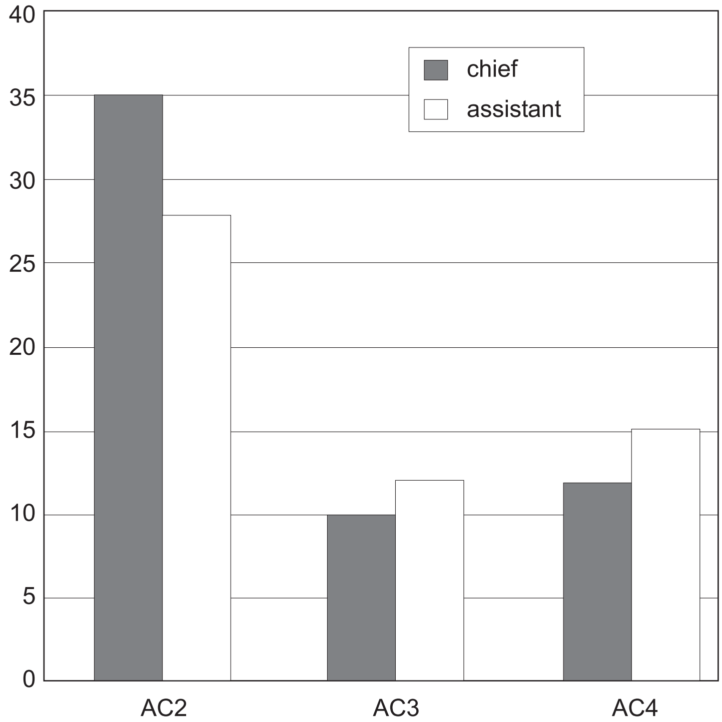

Figure 3. Comparison of frequency percentages of chief and assistant linemen's action categories (ACs).

3.2.3. Hazardous actions in different subtasks

It was obvious that bar-installing and insulator-fixing were hazardous. The ACs of the two subtasks were higher than those of the other subtasks (Tables 7–8). The two subtasks were also time-consuming and full of difficulties. Especially the linemen had to adjust their work posture several times in insulator-fixing, because there were three insulators to be fixed in three different positions. The repetitive fixing work increased the risk. Therefore, more attention should be paid to insulator-fixing and bar-installing subtasks and improvements are necessary.

TABLE 7. Proportion of Action Category (AC) Corresponding to a Subtask (%)

Subtask	AC1	AC2	AC3	AC4
Climbing	93.2	5.9	0.9	0.0
Bar-installing	60.4	28.5	8.5	2.6
Insulator-fixing	28.4	34.7	22.6	14.3
Line-drawing	59.6	33.8	5.3	1.3

4. DISCUSSION

4.1. Task Characteristics and Ergonomics Factors

Thirty linemen were observed in five project fields. A working cycle, which is called a task here, began when a new pole was erected. A

TABLE 8. Proportion of Different Subtasks Corresponding to an Action Category (AC, %)

AC	Climbing	Bar-Installing	Insulator-Fixing	Line-Drawing
AC1	48.3	21.1	18.4	12.2
AC2	1.7	36.8	41.6	19.9
AC3	<0.1	21.2	61.7	18.1
AC4	0.0	15.6	79.8	4.6

lineman climbed the pole, then fixed a bar and an insulator on the top of the pole, and drew a line to a proper position. The sequential cycle began with another newly erected pole when the previous one was finished. The average duration of one cycle in the observed study was ~3.5 h, but this varied greatly among different projects. The level of electricity voltage differentiated power line construction projects. Higher voltage increased workload and thus induced more severe MSDs. A lineman had to finish several repetitive tasks in this project. The number of tasks, which impacted the severity of MSDs, depended on the total length of the power line and the span between poles. However, this risk factor could be ignored in this study since the fixing task focused on a single pole. Any task can be analyzed and divided into several work elements. Though the duration of a work element in one task varied among linemen, the duration percentage differences were relatively insignificant. The mean time percentage and the estimated force of the work elements of 30 linemen can relatively and quantitatively describe the ergonomics factors in power line fixing work. Figures 1–2 illustrate the tasks and the main fixing materials (bar, insulator and power line). Strained body areas and controllable risk factors can describe the ergonomics characteristics of on-pole task in detail (Table 2).

Repetition was another important risk factor for MSDs in work. The number of poles in a project was a major determinant in repetition. Forceful exertions of hand, wrist, low-back and ankle also took place in the handling process. Along with the increasing electricity voltage, the height of the pole and the weight of the line inevitably increased; the difficulty of the project and workload increased accordingly, too. It was evident that the relevant ergonomics risks increased simultaneously.

Muscular force was not measured in this study, but the observer and the subjects reported additional strain caused by the force of muscles recruited to maintain the balance. The linemen commented that the long workday and rest deprivation accompanied by irregular meal times contributed to stress. Irregular meal times and fatigue were studied, though no data on fatigue were directly collected in this study. During conversation, linemen mentioned the high temperature in summer and the low temperature in winter as their health concerns, though the two risk factors had not been observed to be extreme.

4.2. Risk Analysis

The observed ergonomics factors are described in this section; they are grouped according to the part of the body they affect (ankle, knee, low-back, neck, shoulder and wrist). Strain in the ankle came from the whole unbalanced body and not from the flat position of the feet. Strain in the knee came from protracted flexion. Strain in the low-back was caused by three circumstances: static, awkward and protracted postures; bending to fix the insulators to the bar on the pole; and twisting to adjust the bar and draw the line. Strain in the neck came from frequent neck flexion and turning. Strain in the shoulder came from three major factors: reaching to screw the bolts with arms overhead; putting the line on the shoulder to draw it to a proper position; and physical load from lifting the bar or insulator to be fixed to a proper position. Strain in the wrist was mostly caused by adjusting the bar, fixing the insulator, and drawing the line. Subtask and action analyses revealed inevitable hazardous risks. The neck, back, and upper and lower extremities of linemen were at considerable risk. The reasons for those ergonomics risks were as follows: (a) power line fixing is a high altitude job, so linemen face a psychological load; (b) a complicated work environment influences work ability significantly and frequently; (c) working space is strictly confined and a lineman's center of gravity may often be in an unnatural place; and (d) linemen cannot exert themselves as they wish, they have to contract and stretch the relevant muscles technically. Actually, linemen experience non-neutral trunk posture during most of their work time. Ideally, power line fixing should not require static trunk flexion. Once the work begins on the pole, it will inevitably induce ergonomics risks.

4.3. Ergonomics Interventions

Available workspace determines postures for some repetitive tasks such as screwing, fixing and drawing. In a relevant ergonomics intervention, maximum utility of the confined space should be ensured and the work process should require as little unnecessary activity as possible. Mechanical aids can reduce the risk of overexertion, but may need to be custom-made when workspace is restricted. A platform, which can be fixed around a pole and carry several linemen, can eliminate many highly forceful and repetitive activities in awkward postures. Improvement on the drawing and body balancing tools can reduce the need for non-neutral postures and the opportunities for some stresses to the key parts of the body. In many cases, it may be possible to reduce the weight of objects or the strength requirements of a task. Increasing the frequency of rest breaks is advisable when awkward postures are used. Job rotation may be an effective strategy if the job to which the worker is rotated allows relief of muscular fatigue or stress experienced in an unusual or restricted posture. Many experienced linemen mentioned that they deliberately avoided working too fast and found that under a suitable work pace and rhythm it was easier to finish the tasks with reduced ergonomics risk and at the same time without significantly reducing work efficiency. If power lines were all underground, as is the general trend in the industry, there would potentially be no such risk factors. However, it is impractical to change aerial lines into underground cables, and this would probably reveal new ergonomics hazards as well.

Generally speaking, it is very important to gain the supports of employees and employers for implementing any ergonomics intervention strategies. Any successful intervention requires extensive communication and collaboration between researchers, project designers and workers before any intervention is put into practice [13]. Unfortunately, employees and employers, ignoring both the known and the potential ergonomics interventions, considered strain an inevitable result of power line fixing work. Especially the employers were reluctant to introduce new applications that could alleviate those risks. Therefore, real progress in this occupational area requires considerable collaboration between and education of employees and employers.

4.4. Limitation of Study

First, the sample in this study came from the same power line fixing project team. Different project teams worked under different working conditions. The difference could be significant. This study would be improved if the general situation of all linemen were investigated.

Second, field research is challenging; it is difficult to control the working situation and prevent unexpected incidents. For example, the video camera was on the ground, the shooting angle had to change at times. Some actions and body postures could not be recorded in full. This could have influenced the analysis of video sequences.

Third, the quantitative measurements focused on time and frequency. Typical tools and materials were not measured. Although the size of the lines and spans between poles were measured, the load of drawing lines could only be estimated. It is better to use accurate apparatus to measure the physiological indexes of linemen, such as heart rate, blood flow, oxygen consumption, etc. Quantitative physiological data will be convincing evidence in future research.

5. CONCLUSIONS

It was evident that bar-installing and insulator-fixing were hazardous processes. The two subtasks were also time-consuming and difficult. During insulator-fixing linemen had to adjust their work posture several times. Repetitive fixing work increased hazard. The ACs of assistant linemen were higher than those of chief linemen. Power line fixing is a potential source of MSDs. The ergonomics observations made here were designed to focus research efforts to what appeared to be the major contributors to MSDs problems. Specific ergonomics exposure includes awkward postures associated with climbing, screwing and drawing; the repetitive movements of several key body parts during working; and the forces and awkward postures associated with the relevant activities. Generally, this paper presents qualitative and quantitative results to depict and analyze ergonomics hazards of linemen in a power line fixing process.

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